# SAN FRANCISCO BAY MARINA WATER QUALITY PROJECT

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## INTRODUCTION

There are over sixty recreational marinas[1] within the San Francisco Bay Conservation and Development Commission's (BCDC) jurisdiction. The San Francisco Bay Conservation and Development Commission has jurisdiction over San Francisco Bay,[2] salt ponds,[3] managed wetlands,[4] and certain waterways tributary to the Bay.[5] BCDC also has jurisdiction over a shoreline band of land extending 100 feet inland and parallel to the Bay shoreline.[6] Any person or government agency that wishes to place fill, extract materials, or make substantial changes in use of any land, water, or structure within the Commission's jurisdiction must obtain a permit from the Commission.[7]

The *San Francisco Bay Plan* guides BCDC permitting decisions. Its recreation policies encourage new and expanding recreational marinas in the Bay provided: they do not preempt land or water area needed for other priority uses, are feasible from an engineering viewpoint, would not destroy valuable marshes or mudflats, harm valuable fish and wildlife resources, and would not have significant adverse effects on water quality and circulation, and would not result in inadequate flushing.[8] Since the *San Francisco Bay Plan* marina recreation policies were updated in 1982, new scientific understanding and control methods regarding nonpoint source pollution associated with marinas and recreational boating as well as other categories of nonpoint source pollution, such as urban runoff have emerged on a national scale. Nationwide, marinas and recreational boating are considered a category of nonpoint source pollution,[9] and California has adopted this same view in its *2000 Plan for California's Nonpoint Source Pollution Control Program*.[10] However, while some marina water quality studies have been conducted

[1] This report deals mainly with recreational marinas and recreational boating. For the purposes of this report, a recreational marina is defined as any facility with ten slips or more, ten or more moorings, or piers where ten or more boats can tie up, whose main purpose is to serve recreational boating.
[2] Bay jurisdiction being all areas that are subject to tidal action from the south end of the Bay to the Golden Gate and to the Sacramento River line, including all sloughs, and specifically, the marshlands lying between mean high tide and five feet above mean sea level; tidelands (land lying between mean high tide and mean low tide); and submerged lands (land lying below mean low tide). (See The McAteer-Petris Act, California Government Code Section 66610(a))
[3] Salt pond jurisdiction includes only those used during the three years immediately preceding November 11, 1969 for solar evaporation of Bay water in the course of salt production (California Government Code Section 66610(c)).
[4] Manage wetlands jurisdiction consists of all areas diked off from the Bay and maintained during the three years immediately preceding November 11, 1969 as a duck hunting preserve, game refuge, or for agriculture (California Government Code Section 66610(d)).
[5] Certain waterways tributary to the Bay include Plummer Creek in Alameda County, Coyote Creek in Alameda & Santa Clara Counties (to the easternmost point of Newby Island), Redwood Creek in San Mateo County (to the confluence of Smith Slough), Tolay Creek in Sonoma County (to the northerly line of Sears Point Rd. [State Highway 37]), Petaluma R. in Marin and Sonoma Counties (to its confluence with Adobe Creek and San Antonio Cr. to the easterly line of the Northwestern Pacific right-of-way), Napa R. (to its northernmost point of bull Island), Sonoma Cr. (to its confluence with Second Napa Slough), Corte Madera Cr. in Marin County (to the downstream end of the concrete channel on Corte Madera Creek which is located at the U.S. Army Corps of Engineers Station No. 31850 on the Corte Madera Creek flood control projects) (California Government Code Section 66610 (e)).
[6] For descriptions of BCDC's jurisdiction, see California Government Code Section 66610(b).
[7] See California Government Code Section 66632(a)
[8] BCDC. 2003. San Francisco Bay Plan. San Francisco Bay Conservation and Development Commission (BCDC). San Francisco. Reprinted March 2003, p. 48.
[9] USEPA 2001
[10] SWRCB & CCC 2000. *Plan for California's Nonpoint Source Pollution Control Program.* California State Water Resources Control Board, Sacramento, CA and California Coastal Commission, San Francisco, CA.

worldwide and in Southern California, there is little information on the water and sediment quality conditions at San Francisco Bay marinas. BCDC has begun to fill this gap with its San Francisco Bay Marina Water Quality Project. This project involved an extensive literature review and a Pilot Study, "Condition of Sediments in Selected Marinas in San Francisco Bay," conducted by BCDC's National Oceanic and Atmospheric Administration (NOAA) Coastal Management Fellow in collaboration with Moss Landing Marine Laboratories, Marine Pollution Studies Lab.

The literature review examined marina and recreational boating water quality studies from around the world and examined the status of water and/or sediment quality monitoring at San Francisco Bay marinas. This research identified what are assumed to be typical marina and recreational boating-related contaminants on a national scale, identified existing San Francisco Bay marina water quality data, and established the need for additional monitoring in San Francisco Bay marinas to understand whether these contaminants are present in Bay marinas. This literature review is documented in Chapter Two. Literature on management practices for controlling marina and recreational boating-related pollution was also reviewed, although evaluating management practices were not the major focus of the project. Select examples of management practices are included in Appendix E.

The literature review found few existing water or sediment quality studies at San Francisco Bay marinas. BCDC has taken an important step by conducting the Pilot Study, "Condition of Sediments in Selected Marinas of San Francisco Bay," to help address this data gap. The study aimed to answer five study questions:

1. "What is the sediment chemistry concentration in four recreational marinas in San Francisco Bay in regards to the following pollutants associated with marina and recreational boating operations: trace metals (copper, zinc, chromium, lead, arsenic, cadmium), and polycyclic aromatic hydrocarbons (PAHs)?"
2. "Do sediment chemical concentration levels meet or exceed sediment guidelines currently used (or being developed) for California (e.g. Effects Range Low [ERL] and Effects Range Median [ERM])?"
3. "How do sediment concentration levels compare to ambient sediment concentrations calculated for the Bay, and Regional Monitoring Program (RMP) reference stations at Paradise Cove?"
4. "What general water quality conditions exist in the four marinas in regards to dissolved oxygen, temperature, turbidity, pH, and salinity?"
5. "Is there a noticeable difference in contaminant levels found between those four marinas sampled and can we make plausible inferences as to why those differences exist?"

The Pilot Study characterized overall sediment quality conditions and contaminant levels in four San Francisco Bay marinas. As part of the marina selection process for sediment sampling, BCDC staff conducted an extensive phone survey of over forty marinas and developed a marina matrix containing over twenty fields of information on each marina, including marina size, facilities, surrounding land-uses, the existence of municipal storm drain outfalls, and sedimentation rates. Due to funding limitations, the sampling and laboratory analysis did not examine all the potential contaminants identified in the literature review, but did examine heavy metals and petroleum hydrocarbons; both considered to be San Francisco Bay pollutants. Also due to funding limitations, the study was designed to examine if pollutants are present in marina sediments, but did not thoroughly examine the sources of contaminants found in sediments (e.g. whether sediment contamination comes from specific marina and recreational boating-related activities such as boat maintenance activities, or stormwater runoff). But by careful selection of the pilot marina sites to isolate as much as possible different sources of pollution (e.g., by selecting marinas that do not contain municipal stormwater outfalls), inferences could be made on the likely sources of contaminants found in the marinas. While these inferences are not definitive, they provide a reasonable basis for recommended management actions and future monitoring (See Page 8). The Pilot Study also establishes a good model for characterizing water and sediment quality conditions at San Francisco Bay marinas that can be utilized by marina operators, BCDC or other partner agencies in the San Francisco Bay Marinas and Recreational Boating Nonpoint Source Task Force,[11] and it lays the groundwork for future "source identification" studies at marinas, and possible future reviews of the marina water quality policies in the recreation section of the *San Francisco Bay Plan*.

This report documents the San Francisco Bay Marina Water Quality Project in detail, and provides recommendations for addressing marina and recreational boating nonpoint source pollution issues in San Francisco Bay. Chapter One provides background for the project, explaining why and how the project evolved, including the policy context, collaborative process, and funding sources. Chapter Two provides a detailed literature review of marina and recreational boating-related pollutants, the possible sources of those pollutants in marinas, and their monitoring status in San Francisco Bay. Appendix A details the Pilot Study, "Condition of Sediments in Selected Marinas in San Francisco Bay," including the marina selection process and marina matrix, the sampling and laboratory methodology, and laboratory results and discussion. The overall conclusions and recommendations for the San Francisco Bay Marina Water Quality Project are presented on the following pages preceding Chapter One.

[11] A group comprised of marina and boating operators and associations, environmental organizations, and local, state and federal government organizations (Appendix B lists the major active organizations on the Task Force).

**Conclusions**. The following conclusions are based on the major findings of the San Francisco Bay Marina Water Quality Project, including the literature review on marina and recreational boating pollutants and impacts (Chapter Two), the Pilot Study (See Appendix A), and the literature review on marina management practices to control pollutant discharges from marina and recreational boating operations (See Appendix E).

1. **Literature Review Conclusions on Marina and Recreational Boating-Related Pollutants**
   a. Marina and recreational boating operations are not considered a major sources of nonpoint pollution when compared to other categories of nonpoint source pollution (such as urban and agricultural runoff). However, marina and recreational boating operations can inadvertently lead to locally degraded water quality conditions, impacting aquatic organisms and ecosystems. Studies conducted in California and around the world have identified the following marina and recreational boating-related contaminants: heavy metals (copper, zinc, lead, arsenic, cadmium, chromium, tributyltin, and others); petroleum hydrocarbons (including polycyclic aromatic hydrocarbons [PAHs]); sewage/bacterial contamination; and nutrients (nitrogen and phosphorus) (which can lead to lowered dissolved oxygen levels). These contaminants can also originate from non-marina sources.
   b. Studies conducted in California and around the world have found toxic levels of some heavy metals in some marinas. If heavy metals build up to toxic levels (levels of contaminants that cause adverse effects) in the aquatic environment, a wide range of health effects to marine organisms can occur. These can include tumor formation and genetic derangement, tissue inflammation and degeneration, physiological and developmental changes, reproductive abnormalities, changes in feeding behavior, digestive efficiency, and respiratory metabolism, and growth abnormalities and inhibition. All of these effects combined in individual organisms can have detrimental effects on the biological community structure and overall abundance of resident species.
   c. Studies conducted in California and around the world have found toxic levels of some heavy metals in some marinas. If petroleum hydrocarbons, including polycyclic aromatic hydrocarbons (PAHs) build up to toxic levels in the aquatic environment, a wide range of health effects to marine organisms can occur. These include: arrested development, death from oil smothering, cancer, mutations, interference with embryonic development and reproductive failure. All of these effects combined in individual organisms can have detrimental effects on the biological community structure and overall abundance of resident species.

d. Organic matter contained in sewage, and nutrient enrichment from nitrogen and phosphorus, all of which can be discharged from boats in marinas, can result in eutrophication, or algal blooms, causing low dissolved oxygen in waters, fish kills, and the depletion of desirable flora and fauna.

e. Poor flushing and water circulation within a marina basin can contribute to poor water quality conditions, by causing water stagnation, lowered dissolved oxygen levels, and an environment where pollutants can concentrate in water or sediments.

2. **Pilot Study Conclusions on San Francisco Bay Marina Pollution**

a. Sediment quality benchmarks were useful in the detection of contaminants of concern in marina sediments. Published sediment quality guidelines, including "effects range low" (ERL) and "effects range median" (ERM),[12] "threshold effects level" (TEL) and "probable effects level" (PEL),[13] and "PAH consensus guideline values"[14] were useful in determining whether levels of metals and polycyclic aromatic hydrocarbons (PAHs) found in the samples of four pilot marinas could be harmful to aquatic life. Ambient sediment concentrations calculated for San Francisco Bay,[15] were also useful benchmarks in evaluating sediment metals and PAH data. By comparing sediment metals and PAH concentrations within the marinas to Ambient concentrations, one can tell whether levels in the marinas are above what has been calculated to be current conditions for Bay sediments. If several samples within a marina exceeded both "effects range low" (ERL) guidelines and Ambient concentrations, then they were considered "contaminants of concern" in marinas because chemicals at these concentrations have an increased probability of being harmful to aquatic life and are elevated above current conditions for the Bay. Additionally, comparison of marina sediment concentrations to reference samples taken at Paradise Cove, an area considered to be unimpacted by marina or other development activities, provided additional help to confirm or refute these conclusions, by showing whether marina sediment contaminant concentrations were elevated above a non-marina area.

b. In answering study questions 1-3 (See Page 2), the following conclusion was drawn: Study results found copper, zinc and chromium to be contaminants of concern (with copper and chromium being the greatest of concern) in the pilot marinas because their levels could be harmful to aquatic life (exceeded ERLs), and were higher than what has been calculated as current conditions for Bay sediments (calculated

[12] Long and Morgan 1990; Long et al 1995
[13] MacDonald 1992 & 1994; MacDonald et al 1996
[14] Swartz 1999
[15] SWRCB 1998

Ambient values[16]). Arsenic was also found to be of concern because its levels could be harmful to aquatic life (exceeded ERLs), but of less concern because it did not exceed what is considered to be its ambient levels in Bay sediments. All of the contaminant levels found in the marina sediments are not considered extreme, or highly risky to aquatic life (they did not exceed "effects range median" [ERM] guidelines). However, to prevent these contaminants from accumulating at marinas, and potentially increasing to risky levels, marinas and boaters should implement management practices to prevent and minimize discharges of contaminants at marinas (see conclusion #13). Conclusions on the individual contaminants, including their potential marina and recreational boating-related sources are summarized below.

(1) **Copper.** Copper was identified as a contaminant of concern in marinas because sediment concentrations were found to exceed the copper "effects range low" (ERL) guideline (34 mg/kg) in all of the marina samples (40/40), and one sample exceeded the "probable effects level" (PEL) guideline (108.2 mg/kg). This indicates an increased probability that adverse effects to aquatic life could result from copper toxicity in sampled marinas. Additionally, sediment concentrations exceeded the Ambient value for copper (68.1 mg/kg) in more than half of the marina samples (25/40), and exceeded the average reference station value (48.7 mg/kg) in most of the marina samples (35/40). Data from three out of the four marinas demonstrated increasing levels of copper from samples taken at the mouth of the marinas (lower copper levels) to their innermost harbors (higher copper levels). This indicates a possible localized marina-related copper source. The literature review indicates that potential marina and recreational boating-related sources of copper include anti-fouling paints applied to boats and wood preservatives in docks and pilings. Stormwater runoff from marina maintenance areas, leaching of paints from boats stored in the water, as well as pilings and docks containing copper-based wood preservative treatments are potential marina and recreational boating-related pathways of copper to marina waters.

(2) **Chromium.** Chromium (III) is also considered a contaminant of concern in marinas because sediment concentrations were found to exceed the ERL guideline (81 mg/kg) in all of the marina samples (40/40), and several samples approached, and one sample exceeded, the "probable effects level" (PEL)

[16] SWRCB 1998

guideline (160.4). This indicates an increased probability that adverse biological impacts to aquatic life could result from chromium toxicity in marinas. Additionally, the Ambient chromium value (112 mg/kg) was exceeded in most of the marina samples (38/40), and half of the marina samples (21/40) exceeded the average reference station concentration for chromium (135.3 mg/kg). Data from two out of the four marinas demonstrated increasing levels of chromium from the mouth of the marina (lower chromium levels) to the back, innermost harbor samples (higher chromium levels), indicating a possible localized marina chromium source. The literature review indicates that chromium has been used in various capacities in marinas and by boaters and can wash from parking lots, service roads, and launch ramps into surface waters with rainfall.[17] Chromium compounds are used for chrome plating of boat parts, in dyes, and inorganic paint pigments, and as fungicides and wood preservatives in docks and pilings. Chromium can also oxidize and be leached from stainless steel into a water-soluble form. Chromium is also found in the Bay sediments due because of the geology of soils and rocks in the Bay Area.

(3) **Zinc.** Zinc is considered a contaminant of concern in marinas because sediment concentrations were found to exceed the ERL guideline (150 mg/kg) in a third of the marina samples (14/40) indicating a low to moderate probability that adverse affects to aquatic life could result from zinc toxicity. Additionally, zinc concentrations exceeded the Ambient value for zinc (158 mg/kg) in a quarter of the marina samples (11/40), and the average reference station concentration (99.2 mg/kg) in most of the marina samples (32/40). Two out of the four marinas exhibited increasing levels of zinc from the mouth of the marinas (lower zinc levels) to their back innermost harbors (higher zinc levels), indicating a possible localized marina-related zinc source. The literature review indicates that potential marina and recreational boating-related sources of zinc include anti-corrodants for metal hulls, engine parts, and boat propeller shafts, anti-fouling paints, motor oil, tires, and wood preservatives in docks and pilings. Runoff from marina parking lots, launch ramps, and maintenance areas, and leaching from boats stored in the water as well as pilings and docks are potential marina-related pathways of zinc to marina waters.

[17] U.S. EPA 2001

(4) **Arsenic.** Arsenic is considered a contaminant of concern in marinas because sediment concentrations were found to exceed the ERL guideline (8.2 mg/kg) in a majority of the marina samples (36/40) indicating a low to moderate probability that adverse affects could occur to aquatic life. Few samples (1/40) exceeded the Ambient value (15.3 mg/kg) or average reference station concentrations (12.4 mg/kg) (5/40 samples) for arsenic, so arsenic isn't as much of a concern in marinas as copper, chromium, or zinc. The literature review indicates that potential marina and recreational boating-related sources of arsenic include paint pigments, wood treatments, and pesticides applied to landscaping. While marine paint and coating compounds made with arsenic are no longer used because of their toxicity, arsenic may still be present on older boats. Runoff from maintenance areas, landscaping areas, and leaching from boats stored in the water and docks and pilings are potential marina–related pathways of arsenic to marina waters.

c. Measured concentrations of cadmium, lead and polycyclic aromatic hydrocarbons (PAHs) were generally low in the pilot marinas and are not considered contaminants of concern in the pilot marinas.

d. In answering study question four (water quality measurements), it was found that dissolved oxygen (DO) in two of the pilot marinas was low in bottom waters at several locations and may present a risk of hypoxia (low available oxygen) to aquatic life (DO range: 2.4 mg/L-9.3 mg/L). However, these measurements represent only a snapshot in time. Dissolved oxygen levels naturally fluctuate throughout the day. In order to get accurate assessments of dissolved oxygen trends, it is necessary to take multiple samples at different times of day, and during different tidal regimes. Therefore, it is not possible to draw definitive conclusions about dissolved oxygen levels in the marinas sampled. Additional monitoring of oxygen levels is recommended to improve our understanding of oxygen saturation conditions in marinas.

e. Study question five was not completely answered by this Pilot Study. Ascertaining the specific source of pollutants in the marinas and understanding why differences exist between the marinas was beyond the scope and budget of the Pilot Study. Some preliminary conclusions were drawn, which should be tested with further research: Statistical analysis comparing contaminant levels between the four marinas sampled showed significant differences in metals levels between the marinas. The smallest marina had significantly lower metal concentrations than the other three marinas. Copper, cadmium, and zinc levels were often positively correlated

suggesting possible common sources, such as bottom paints. Arsenic did not correlate or was negatively correlated with the other metals indicating a possible separate source in the marinas. Additional research is suggested to increase understanding of specific sources of pollution found in marinas.

f. Additional monitoring and analysis is needed to strengthen our understanding of water and/or sediment quality conditions at marinas in the Bay, to increase our understanding of specific sources of pollution found in marinas, and the impact of contaminant levels on aquatic life (see recommendation 5a-d).

g. Results from the marina selection process and development of a marina matrix for the Bay found that many marinas in San Francisco Bay contain municipal storm drain outfalls, which may discharge stormwater and dry weather flows into the marinas. Marinas with municipal storm drains were not selected for the Pilot Study in order to isolate marina and recreational boating-related pollution from pollution coming from municipal storm drain outfalls. More research is needed, however, to understand the impacts of stormwater and dry weather flows on water and sediment quality conditions at other marinas in the Bay.

3. **Literature Review Conclusions on Management Measures**

   a. Although there are few contaminant-specific management practices, there are general low-cost management practices that can address multiple contaminants, such as maintenance area, parking lot, and landscaping runoff treatment and prevention strategies, and clean boating educational programs for marina tenants and other boaters.

   b. Boaters can help to prevent copper contamination in Bay waters by implementing alternative, non-toxic anti-fouling strategies instead of applying copper-based anti-fouling paints to boat hulls.

4. **Other Conclusions**

   a. Collaboration with regulatory agencies such as the San Francisco Bay Regional Water Quality Control Board, research institutions such as San Francisco Estuary Institute, representatives from the marina and recreational boating community, and environmental non-government organizations is essential to furthering our understanding of, and addressing marina and recreational boating nonpoint source pollution issues in the Bay.

**Recommendations.** An adaptive management approach should be followed to address marina and recreational boating nonpoint source pollution issues in San Francisco Bay. This approach involves immediate management actions that reflect our current understanding of marina and recreational boating-related nonpoint source pollution in the Bay, continued studies that address our incomplete understanding of marina and recreational boating-related nonpoint source pollution, and in the future adjusting management actions, as appropriate, to reflect changes in our scientific understanding of marina and recreational boating impacts and effectiveness of management practices.

1. **Management Actions**
    a. **Management Practices.** Consistent with Bay Plan water quality policies, the Commission should require that all permitted projects, including new and expanding marinas, and marinas undergoing substantial renovations should, to the best extent practicable, implement management practices, such as controlling runoff from marina parking lots, other paved areas, and maintenance areas, designed to prevent contaminants from entering the Bay.
    b. **Education.** The Commission should continue to collaborate with and support educational programs that promote environmentally friendly boating practices, such as the Boating Clean and Green Campaign (conducted by the California Coastal Commission in conjunction with the California Department of Boating and Waterways and Contra Costa County) and the California Clean Boating Network. Additionally, the Commission should encourage the development of educational programs that educate boaters on management practices to prevent contaminants of concern, such as copper and zinc, from entering Bay waters. Education programs should include non-toxic anti–fouling strategies for boats to help prevent copper contamination in marina and Bay waters.
    c. **Flushing.** The Commission should require permit applicants for new marina projects to submit a hydrological report assessing how the proposed marina design will affect the flushing capabilities of the marina basin.
    d. **Self Monitoring.** To better understand water and sediment quality at marinas, and to evaluate the effectiveness of management practices in preventing contaminants from entering marina waters, marina operators and boating organizations should establish volunteer self-monitoring programs.

2. **Further Studies**
   a. The Commission should consider partnering with or encouraging other relevant agencies (such as the San Francisco Regional Water Quality Control Board and the San Francisco Estuary Institute's Regional Monitoring Program) to pursue special funding to:
      (1) Conduct source identification studies in the four pilot marina sites for copper, chromium, zinc, and arsenic to gain further understanding of the sources of these contaminants in marinas.
      (2) Analyze archived benthic community samples from the four marina pilot sites, to gain further understanding of potential impacts of contaminants to aquatic life.
      (3) Conduct sediment and water characterization studies at additional marinas in the Bay. These studies should include analyses for the major contaminants of concern identified in the Pilot Study, as well as other potential marina and recreational boating-related contaminants and conventional water quality parameters.
      (4) Explore the impacts of urban stormwater runoff and dry weather flows on marina water and sediment quality in the Bay, and support studies that examine the relative contribution of pollutants from urban stormwater and dry water flows and marina and recreational boating-related activities in marinas in San Francisco Bay.
   b. The Commission should consider pursuing special funding to conduct a program that comprehensively analyzes the physical, chemical, and biological testing data already required by the Dredged Material Management Office (DMMO) of applicants for a marina dredging permit, as a cost effective way to increase understanding of contaminants of concern in San Francisco Bay marinas.
3. **Collaboration**
   a. Provided funding is available:
      (1) The Commission should continue to collaborate with existing sewage/bacteria monitoring programs in San Francisco Bay marinas, such as the WaterKeepers Northern California's monitoring program, and consider using their data and reports as appropriate in future possible marina water quality policy updates.
      (2) The Commission should continue to work collaboratively with marina operators, recreational boaters, federal, state, and local government agencies, nonprofits, and others to address marina and recreational boating nonpoint source pollution in the Bay, by providing a forum as needed to address these issues.

(3) The Commission staff should continue to participate on state-wide inter-agency working groups charged with addressing marina and recreational boating-related nonpoint source pollution, such as copper working groups that examine the impacts of copper anti-fouling paints on water quality in marinas.

(4) The Commission should continue to forge strong relationships with monitoring organizations, such as the San Francisco Estuary Institute, the San Francisco Bay Regional Water Quality Control Board, and WaterKeepers Northern California, and encourage water and sediment quality monitoring in San Francisco Bay marinas, and the provision of those data to the Commission.

CHAPTER 1

## BACKGROUND OF THE SAN FRANCISCO BAY MARINA WATER QUALITY PROJECT

Pollutants reach the Bay from many different sources and pathways.[1] Pollution from distinct, identifiable sources, such as treated municipal waste and industrial discharges are referred to as "point source" discharges. "Nonpoint source" pollution (NPS) does not come from a distinct source or pathway. It can include, among others, metals, petroleum hydrocarbons, sediments, nutrients and bacteria from stormwater runoff from streets and parking lots, fuel and oil spills and maintenance activities at marinas, and remobilization of bed sediments from "hot spots."[2] All of these pollutants can be transported directly into the Bay. Nonpoint source pollution is one of the top threats to ecological health and human health in San Francisco Bay. The State Water Resources Control Board (State Board) has designated areas of the Bay as impaired waterbodies for metals and other contaminants that can be associated with marinas and recreational boating as well as other sources such as urban runoff and historical industrial pollution. These include, but are not limited to, copper, lead and TBT in Oakland Inner Harbor sediments, lead and zinc in San Leandro Bay sediments, and Polycyclic Aromatic Hydrocarbons (PAHs) in sediments of Castro Cove, Richmond, the San Francisco Bay Central Basin, Islais Creek, Oakland Inner Harbor, and San Leandro Bay. (See Chapter Two for more information on Bay pollution).[3]

**BCDC's Nonpoint Source Work Program and Marinas.** States are required to control or prevent NPS pollution pursuant to the 1987 amendments to the federal Clean Water Act and the 1990 Coastal Zone Management Act reauthorization amendments. The Plan for California's Nonpoint Source Pollution Control Program (California Plan) identifies 61 specific management measures, which are implemented through management practices, for the control of nonpoint source pollution from agriculture, forestry, urban areas, marinas and recreational boating, hydromodification, and wetlands, riparian areas, and vegetated treatment systems. The California Plan identifies the San Francisco Bay Conservation and Development Commission (BCDC) as an implementing agency with authority and jurisdiction over the following categories of NPS pollution in the Bay: (1) urban; (2) marinas and recreational boating; (3) hydromodification (channel modification); and (4) wetlands, riparian areas and vegetated treatment systems.

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[1] Pollutants can enter estuaries such as San Francisco Bay through multiple point and nonpoint *sources* (activities leading to the release of contaminants contained in boat hull paints, automobile combustion byproducts, and pesticides) and numerous *pathways* (routes through which contaminants are transported such as direct water contact with the product [boat hull paints], urban and agricultural runoff).

[2] "Hot Spots" are areas in the Bay, determined by the San Francisco Regional Water Quality Control Board, that have high levels of historical contaminants (or legacy contaminants) in the sediments.

[3] 2002 CWA Section 303 (d) List of Water Quality Limited Segments. San Francisco Bay Regional Water Quality Control Board. Approved by U.S. EPA July 2003.

In February 2000, the California Resources Agency directed BCDC to develop a five-year nonpoint source pollution control plan. In response to the Resources Agency's directive, BCDC developed and adopted a *Nonpoint Source Pollution Report and Proposed Work Program* (Work Program) consistent with the California Plan that addresses BCDC's role in controlling nonpoint source pollution from urban runoff, hydromodification (alteration of waterways), alteration of wetlands and riparian areas, and marinas and recreational boating in the Bay.

BCDC has little control over the vast majority of polluted runoff coming into San Francisco Bay because the watershed for the Bay drains approximately 40 percent of the State, including a portion of the State of Oregon-areas far beyond the Commission's jurisdiction. Generally, the Commission's jurisdiction covers San Francisco Bay and extends only 100 feet landward of the mean high tide line. Therefore, the Commission has focused its nonpoint source pollution Work Program on marinas and recreational boating because it has specific jurisdiction and authority over these uses.

San Francisco Bay is a popular place for recreational boating. The Bay has over sixty recreational marinas with combined boat storage capacity of over 22,000, including wet slips and dry storage.[4]

**Need for Data on San Francisco Bay Marina Water Quality Conditions.** In November 2001 BCDC held a public workshop to discuss marina and recreational boating-related nonpoint source pollution issues in San Francisco Bay. Several representatives from marina and recreational boating organizations, individual harbormasters and boaters, environmental organizations, and representatives from local, state, and federal government agencies were in attendance. Out of these discussions, it became clear that there was a need for "additional information" and "concrete data" on water quality conditions at San Francisco Bay marinas, and that increased marina and boater involvement in the process was needed.

Although the U.S. Environmental Protection Agency (U.S. EPA), the State Board, and the California Coastal Commission consider NPS from marinas and recreational boating a primary concern for California,[5,6] few marina monitoring programs are in place in San Francisco Bay to determine whether, and to what extent, marina and recreational boating-related pollution is a problem. Because many of the marinas in San Francisco Bay do not have point source discharges and are not involved in equipment cleaning and maintenance activities, they are not

[4] California Department of Boating and Waterways (DBW), California Coastal Commission, and personal communication with marinas in the Bay (2003-2004).
[5] U.S. EPA 2000. A Summary of the National Water Quality Inventory: 1998 Report to Congress. EPA Office of Water. EPA 841-5-00-001.
[6] SWRCB & CCC 2000. *Plan for California's Nonpoint Source Pollution Control Program.* State Water Resources Control Board, Sacramento, CA and the California Coastal Commission, San Francisco, CA

actively regulated under the Statewide Industrial Stormwater General Permit,[7] but may still generate or discharge many pollutants. Further scientific study is needed to determine the water quality impacts of marinas in San Francisco Bay.

**BCDC Obtains Grant and NOAA Coastal Management Fellow to Conduct Marina Study.** In October 2001 BCDC staff submitted a proposal to the National Oceanic and Atmospheric Administration's (NOAA) Coastal Services Center (CSC) to receive a NOAA Coastal Management Fellow ("fellow"). Working with BCDC staff, the fellow would set up a scientifically based volunteer water quality monitoring program for San Francisco Bay marinas, and conduct pilot monitoring projects at selected marinas. NOAA awarded BCDC a fellow to implement the project for 2002-2004, and in August of 2002, she began the San Francisco Bay Marina Water Quality Project.

In July 2002 and 2003, BCDC received funding from the NOAA nonpoint source pollution implementation fund for equipment and consultant services, to be used for the Pilot Study: "Condition of Sediments in Selected Marinas in San Francisco Bay" ("Pilot Study").

**San Francisco Bay Marinas and Recreational Boating Nonpoint Source Task Force is Formed.** In September 2002, BCDC staff met with interested parties, such as marina and operators and associations, recreational boaters, environmental organizations, and local, state and federal government organizations, to formally establish the San Francisco Bay Marinas and Recreational Boating Nonpoint Source Task Force ("Task Force"). Participation was open to all interested parties (Appendix C lists the major active organizations on the Task Force). At this meeting the Task Force expressed its desire to be an advisory committee for the project, and BCDC and the Task Force collectively developed overall objectives for the project. These objectives were refined and added to over the next year, as the project became more defined.

**San Francisco Bay Marina Water Quality Project Objectives**

1. Establish baseline information, through literature review, data compilation and field sampling, on the condition of selected marinas in San Francisco Bay regarding selected pollutants, to provide a better understanding of existing water and sediment quality conditions at marinas in San Francisco Bay.
2. Use field sampling and laboratory analysis to better identify pollutants of concern, to measure the degree of contamination and identify where pollution does and does not occur.
3. Use field sampling, laboratory analysis, and literature review to gain a better understanding of possible sources of pollution in marinas in San Francisco Bay.

[7] Issued by the San Francisco Regional Water Quality Control Board under the National Pollution Discharge Elimination System (NPDES) program. Currently only marinas with boatyards are actively regulated under this permit program, although all marinas that have fuel docks, outdoor chemical storage, or boat washing areas should possess conditional industrial stormwater permits.

4. Use field sampling, laboratory analysis, and literature review to guide BCDC and other relevant state agencies as to whether additional controls, educational programs, and/or expanded marina monitoring programs are warranted to control marina and recreational boating-related nonpoint source pollution.

**Literature Review**. Once objectives were developed, BCDC staff conducted an extensive literature review of other monitoring programs and marina water quality studies worldwide, and searched for San Francisco Bay specific data on water quality at marinas. This review included studies on water, sediments, and marine organisms (such as mussels), all three of which are mediums for studying water quality. Information and knowledge gained from the literature review helped in developing a conceptual design for the Pilot Study. BCDC staff presented San Francisco Bay specific information to the Task Force in January 2003. Chapter Two summarizes this literature review by giving an overview of marina and recreational boating-related pollution, and referencing California-specific data. Appendix B provides additional information on worldwide marina studies.

**Pilot Study Technical Advisory Committee.** Due to the technical nature of the Pilot Study, BCDC staff formed a Technical Advisory Committee (TAC) in December 2002 to supplement the Task Force. This committee was comprised of scientists from the San Francisco Regional Water Quality Control Board (San Francisco Regional Board), California State Water Resources Control Board (State Board), San Francisco Estuary Institute (SFEI), NOAA Coastal Services Center, California Coastal Commission (CCC), Moss Landing Marine Labs (MLML), and representatives from Recreational Boaters of California (RBOC) and the California Association of Harbor Masters and Port Captains. This committee convened in April 2003, July 2003, and May 2004. In April 2003 the group reviewed the conceptual study design for the Pilot Study, and in July 2003 the group selected four marinas for the study, based on criteria developed by BCDC staff in consultation with the TAC, Task Force and MLML. Budgetary constraints restricted the study to four marinas. Appendix A describes this marina selection process in detail.

**BCDC Inter-Agency Agreement with Moss Landing Marine Labs.** In June 2003, BCDC entered into an inter-agency agreement with Moss Landing Marine Laboratories (MLML), San Jose State University Foundation, to conduct sampling, analysis and reporting for the Pilot Study.

In August 2003, BCDC staff, in conjunction with MLML, began implementation of the Pilot Study, and sampled sediments at the four marinas. Appendix A contains the Pilot Study report.

CHAPTER 2

# LITERATURE REVIEW:
# OVERVIEW OF MARINA AND RECREATIONAL BOATING-RELATED POLLUTION

Marina and recreational boating operations can inadvertently lead to locally degraded water quality conditions, though they are not considered a major source of nonpoint source pollution to our nation's waterways when compared with other categories of nonpoint pollution (such as urban and agricultural runoff).[1] "Marinas and Recreational Boating" is included as a category in *California's Nonpoint Source Plan*.[2] Marina and recreational boating operations can contribute pollutants such as heavy metals from boat hull paints and plating accessories, engine components, engine oils, and wood treatments in pilings and docks; petroleum hydrocarbons from fueling, oil spills, and fuel combustion from outboard motors; bacterial contamination from boat sewage discharges; nutrients, such as nitrogen and phosphorus, from gray water discharges, landscaping fertilizers, and detergents; and others. Poor flushing and water circulation within a marina basin can contribute to poor water quality conditions, by causing water stagnation, lowered dissolved oxygen levels, and an environment where pollutants can concentrate in water or sediments.

Although some marina studies have been conducted in Southern California and worldwide, few specific marina studies exist in San Francisco Bay. While there are several water and sediment quality monitoring programs for San Francisco Bay as a whole, few examine conditions at marinas. Much of the existing data (e.g. bacteria) is sporadic and disconnected, and studies that have marina stations are do not focus on specific marina-related questions. These gaps were the major impetus for BCDC's Pilot Study: "Condition of Sediments in Selected Marinas in San Francisco Bay," which analyzed metals and hydrocarbons in sediment of four San Francisco Bay marinas (see Appendix A). This effort is a crucial first step towards understanding water and sediment quality conditions in San Francisco Bay marinas, and helps to direct future programs toward identified problems.

**Structure of Chapter.** This chapter presents a literature review of potential pollutants and sources[3] associated with marinas and recreational boating.[4] It is important, however, to recognize that these pollutants can also come from other sources and pathways of nonpoint pollution, such as urban and agricultural runoff.[5] The sections below focus on the following pollutants:

- Heavy metals
- Petroleum hydrocarbons
- Sewage
- Nutrients

Each of the pollutant sections is organized into the following subsections:

- Summary. This subsection provides a summary conclusion about the pollutant's presence in the Bay and the status of its monitoring in San Francisco Bay marinas.
- Description of Pollutant. This subsection provides a technical description of the pollutant, and its general behavior in the marine environment.
- Effects of Pollutant on Marine Life. This subsection describes potential adverse effects of the pollutant on marine organisms and communities, and human health impacts, if relevant.
- Pollutant in San Francisco Bay. This subsection discusses the status of the pollutant in San Francisco Bay as a whole, which provides context and justification for examining this pollutant at the smaller-scale marina level.
- Potential Sources and Pathways of Pollutant in Marinas. This subsection discusses marina and recreational boating-related sources of the pollutant, other sources of the pollutant, and how these pollutants can enter marina waters.
- Pollutant in California marinas. This subsection describes existing data and studies on the pollutant in California marinas.
- Pollutant in San Francisco Bay Marinas. This subsection describes existing data and studies on the pollutant in San Francisco Bay marinas. It provides context and justification for inclusion or non-inclusion of this pollutant in BCDC's Pilot Study.

Although BCDC's Pilot Study (See Appendix A) does not sample and analyze all of the pollutants described in this chapter, this chapter provides background information on most of the known possible pollutants. This gives a more complete picture of marina and recreational boating-related pollutants nationwide, and provides context for the Pilot Study.

Information for this literature review was obtained from library and internet searches, interviews with water quality professionals in the Bay Area (federal, state, and local government agencies), and with the assistance of the San Francisco Bay Marinas and Recreational Boating Nonpoint Source Task Force. Additionally, BCDC staff faxed a survey to sixteen well-known marinas in the Bay, to ask if the marina, or anyone else, had ever conducted water quality monitoring in their marinas. Marina harbormasters completed and returned fourteen of these questionnaires.

#### Heavy Metals

1. **Summary.** Heavy metals contaminate waters and sediments throughout San Francisco Bay. Marina and recreational boating-related activities can introduce heavy metals to Bay waters, specifically within marina basins. While studies have been conducted in Southern California and worldwide (See Appendix B for studies outside of California), there are few specific studies on heavy metals contamination in marinas of San Francisco

Bay. BCDC's Pilot Study has begun to fill this gap by sampling and analyzing sediment chemical concentrations in four San Francisco Bay marinas (see Appendix A). The following sections provide a description of heavy metals, effects on marine life, potential sources and pathways in marinas, and conclude by documenting existing studies on metals in California and San Francisco Bay marinas.

2. **Description of Heavy Metals.** In literature about metals in aquatic systems the term "heavy metals" is often used interchangeably with "trace metals," "toxic metals," "trace elements," and "trace constituents." Heavy metals have generally been associated with contamination in aquatic environments and toxicity to plants and wildlife. They include mercury, copper, cadmium, arsenic (a metalloid), lead, selenium, tin, chromium, zinc, and others. There are also organometals (e.g. Tributyltin [TBT], alkylated lead, and methylmercury), which are extremely toxic to marine organisms, as well as to humans. Heavy metals generally accumulate in sea-bottom sediments because their particle-reactive properties allow them to sorb easily to suspended sediments and other particulate matter.6 Heavy metals can also remain in the water column in dissolved form, or by attaching to small suspended particles.7 The major metals of concern found in some marinas worldwide include copper, tributyltin (TBT), lead, zinc, arsenic, chromium, and cadmium (see below and Appendix B for studies documenting these metals in marinas).
3. **Effects of Metals on Marine Life.** If heavy metals build up to toxic levels (levels of contaminants that cause adverse effects) within a marine organism's system, a wide range of health effects can occur (See Table 1). Pathological responses to metals in organisms include: neoplasm (tumor) formation and genetic derangement, tissue inflammation and degeneration, physiological and developmental changes, changes in feeding behavior, digestive efficiency, and respiratory metabolism, and growth abnormalities and inhibition. Organometals (like TBT) can damage reproductive and central nervous systems. All of these effects combined in individual organisms can have detrimental effects on the biotic community as a whole.8

   It is important to note that the actual toxicity of a metal to a marine organism depends on an organism's ability to take up, store, remove or detoxify the metal. Before an organism can take up a metal, the metal must be "bioavailable," or accessible to the organism. Bioavailability is strongly influenced by whether the metal is in a dissolved or solid state (sorbed on particles, as colloids, etc.).[9] Metals in sediments can become bioavailable to aquatic organisms in the water column by dredging and bioturbation (organism activity that stir up sediments), or released from sediments through

remineralization[10] or changes in water pH.[11] When metals are contained in sediments, benthic organisms can become exposed to them. These contaminants can then bioaccumulate in animal tissues and move up the food chain.[12]

4. **Metals in San Francisco Bay.** The San Francisco Estuary Institute's (SFEI) Regional Monitoring Program (RMP) has been tracking the status and trends of contaminants in San Francisco Bay since 1993. It is important to note that sample stations are located primarily in the middle of the Bay, and not the margins where the marinas are located (recent study design changes include more near-shore area sampling sites). In sediment samples taken in the North Bay, copper, chromium, and nickel have exceeded sediment guidelines.[13,14] In the Carquinez Strait, sediment samples containing copper and chromium have exceeded sediment quality guidelines. In the Central Bay, sediment samples have exceeded guidelines for chromium, copper, and nickel. In the South Bay, chromium, copper, mercury, and nickel have exceeded sediment guidelines.[15] Currently the entire San Francisco Bay is listed as an impaired water body for mercury on the State's 2002 303 (d) list. Mission Creek sediments are listed for copper, lead, zinc, and chromium. Oakland Inner Harbor sediments are listed for copper, lead and TBT. San Leandro Bay sediments are listed for lead and zinc.[16] Copper is on the 2002 303 (d) monitoring list for the entire Bay.[17]
5. **Potential Sources and Pathways of Metals in Marinas.** Regarding marina and recreational boating activities, metals are contained in marine paints, anti-corrodants, and other marine products and materials (See Table 1). According to a report on Puget Sound boatyards in Washington State, copper, lead, and zinc are typical constituents of boatyard and shipyard pressure-washing wastewater, with copper and lead labeled as "contaminants of concern" (consistently exceeded the sanitary sewer limits).18 In recent years, California boatyards have taken steps to decrease contamination of stormwater runoff and have installed special equipment to contain wastewater, due to National Pollutant Discharge Elimination System (NPDES) permit conditions,19 however discharges can still occur from maintenance areas not covered under the NPDES program, in-water maintenance work, and/or passive leaching of hull paints and engine components from boats in the water.20 Metals are also contained in wood preservatives used in pilings and docks and can enter the marine environment through passive leaching. Metals are also present in boat engine oils and bilge water, both of which can inadvertently be discharged into marine waters.21 (See below and Appendix B for studies documenting metals in marinas). Metals contained in bottom sediments can be reintroduced to the water column through dredging, boat propeller action, construction

activities, or other activities that stir up the bottom sediments. Metals can also enter marinas through urban runoff and remobilization of sediments from other contaminated areas.

a. **Copper.** Copper-based paints are the most popular anti-fouling paints for boat hulls. The goal of these paints and the biocides contained within (such as cuprous oxide) is to retard the growth of encrusting organisms, such as barnacles. These antifouling coatings slowly release copper in their most toxic form to retard this growth and maintain a smooth surface on the hull.[22] In San Diego Bay, the majority of dissolved copper loading comes from antifouling paints from recreational boats and navy ships, rather than from urban runoff and direct atmospheric deposition.[23] Copper can be released from the boat hull through land-based maintenance and sanding activities, underwater hull cleaning, and through passive leaching as described above. Laboratory experiments conducted by the Southern California Coastal Water Research Program (SCCWRP) found that on a mass basis, ninety-five percent of the copper loading from recreational hull coatings occurs via passive leaching, as opposed to underwater hull cleaning.[24]

   Copper-based products are often used as wood preservatives, such as chromated copper arsenate (CCA) and ammoniacal copper zinc arsenate (ACZA), used in marina docks and pilings. Scientific studies suggest that arsenic, copper, and chromium, and zinc can leach from CCA and ACZA treated wood over time.[25] Currently the San Francisco Regional Water Quality Control Board (San Francisco Regional Board) encourages the use of cement, steel and plastic piles instead of CCA and ACZA in marine waters, but there are no formal regulations or policies regarding their use.[26] BCDC is considering not allowing the new use of CCA or AZCA treated wood in the Bay unless it is wrapped in a manner acceptable to the Regional Board and maintained continually.

   In addition to the above marina-related sources, urban runoff can also contain copper and can enter marina waters through municipal storm drains, creeks, and over-land drainage.

b. **Tributyltin.** Before being banned for most marine uses because of its high toxicity to the marine environment, tributyltin (TBT) was used as the toxic agent in anti-fouling paints, outboard motors, and lower drive units.[27] Acute toxic effects to aquatic organisms, such as clam larvae, have been documented at levels as low as 6 parts per trillion (ppt).[28] In 1989 the U.S. EPA limited the use of TBT. It is still permitted on aluminum boats, vessels over 82 feet, and aluminum outdrives, if they are painted

by licensed applicators. [29] In 1988 the State Board conducted an in depth review of TBT, which included review of water and sediment studies. Researchers found that TBT was one of the most toxic chemicals to marine aquatic life, with adverse effects occurring at levels lower than 20 parts per trillion (PPT). As a result, water quality objectives were established for California's Ocean Plan, and Bays and Estuaries plans. The report also documents the widespread occurrence of the contaminant over marine and freshwater habitats across the state. In San Francisco Bay, all sixteen marinas sampled by a joint UC/State Board effort had detectable concentrations of butyltins. Ninety percent of samples taken in California as a whole exceeded State Board criteria (sixty-one percent of non-marina samples also exceeded the criteria). Significant amounts were found in water, sediments, and mollusks. The threat of TBT to human health was also documented in the report. It is assumed to be toxic to humans, because it is toxic to mammalian immune systems. TBT has been found to bio-accumulate in food organisms in California, including fish and shellfish.[30]

c. **Zinc.** Zinc anodes are commonly used as anti-corrodants for metal hulls, engine parts, and boat propeller shafts.[31] Zinc is also contained in boat anti-fouling paints,[32] motor oil, and tires, and is a common constituent of runoff from marina parking lots,[33] and zinc is a component of the wood preservative ACZA, which is used in marine pilings, docks and piers (see Copper section for more information on ACZA). In addition to these marina-related sources, zinc can also enter marina waters through municipal storm drains, creeks, and over-land drainage.

d. **Lead.** Lead compounds are contained in some sailboat keels, marine paints, and lead acid batteries. It can be discharged into the marina environment from leaching of sailboat keels,[34] and corrosion of fittings and lead acid batteries.[35] For example, if batteries are not properly disposed of or stored on the dock or near a waterway, they can leach into the water. Additionally, stormwater runoff from marina parking lots and municipal stormdrains, creeks and overland drainage can act as a conduit for lead contamination in a marina.

e. **Arsenic.** Arsenic is often contained in paint pigments, wood treatments, and pesticides.[36] While marine paint and coating compounds made with arsenic are no longer used because of their toxicity, arsenic is still used in CCA (chromated copper arsenate) treated wood[37] (see Copper section for more information on CCA), and may still be present on older boats. Urban runoff can also contain arsenic and enter marina waters through municipal storm drains, creeks and overland drainage.

f. **Chromium.** Chromium has been found in dredged materials and waters of some marinas.[38] The U.S. EPA indicates that chromium has been used in various capacities in marinas and by boaters and can wash from parking lots, service roads, and launch ramps into surface waters with rainfall.[39] Chromium compounds are used for chrome plating, as dyes, as inorganic paint pigments, and as fungicides and wood preservatives in docks and pilings. Chromium is a component of chromated-copper-arsenate (CCA) treated wood (see Copper and Arsenic sections for further information on CCA). In addition to these marina-related sources, urban runoff can also contain chromium and it can enter marina waters through municipal storm drains, creeks, and over-land drainage.

g. **Cadmium.** Cadmium compounds are used in the metal plating and battery industry, and as stabilizing agents in many polyvinyl chloride (PVC) products, and many of these products are used on boats. Additionally, cadmium is a component of gasoline, diesel fuel, and lubricating oils. In addition to these marina and recreational boating-related sources, cadmium can enter marina waters through municipal storm drains, creeks, and over-land drainage.

6. **Metals in California Marinas.** California studies have found elevated levels of metals in sediments of marinas and harbors. The Southern California Bight '98 regional monitoring survey found that the highest sediment concentrations for metals and other target analytes were found in bays and harbors, with marinas accounting for a large portion. Copper, zinc, lead, and polycyclic aromatic hydrocarbons (PAHs) were among the most elevated contaminants in this strata (in addition to mercury, chlordanes, and PCBs).40 In the California Bight's toxicity survey, within harbors, marina samples had the highest frequency of toxicity (thirty-eight percent). Twenty-seven percent of the area classified as 'high concern' for toxicity occurred in marinas (more than ports/industrial harbors, rivers, and publicly owned treatment works [POTW] discharge areas).41 Shelter Island Yacht Basin (Shelter Island) in San Diego Bay has been extensively studied for copper. To illustrate, Johnston (1990) documented increasing concentrations of dissolved copper (and organotins) in water samples along a gradient from the mouth of the yacht basin to the innermost moored vessels.[42] A decrease in species diversity of marine fouling communities, paralleling an increase in dissolved copper (and organotin) levels was observed, demonstrating their toxic effects on some marine organisms.[43] Most recently, the San Diego Regional Water Quality Control Board (San Diego Regional Board) conducted a survey for dissolved copper concentrations in Shelter Island water samples and found continued high dissolved copper concentrations (as high as

8$\mu$g/L).[44,45] Adverse effects on aquatic biota were also found. In a 2000 toxicity survey conducted by the San Diego Regional Board in Shelter Island, developmental toxicity was observed in the mussel, *Mytilus edulis*, at stations with the high concentrations of dissolved copper, while no toxicity was observed in low concentration stations.[46]

7. **Metals in San Francisco Bay Marinas.** There is very little known about the extent of metals contamination in San Francisco Bay marinas, besides the extensive tributyltin study that was conducted by the State Board in 1988 (See Tributyltin section, p. 21), and sediment testing from maintenance dredging activities. Because of this lack of data, metals were sampled and analyzed as part of BCDC's Pilot Study (See Appendix A). The following paragraphs describe three monitoring efforts that included sampling for metals in San Francisco Bay marinas.
    a. **NOAA National Status & Trends Bioassessment Program.** In 2000 and 2001, researchers from the National Oceanic and Atmospheric Administration (NOAA) sampled sediment at five marina stations in San Francisco Bay, as part of its regional Status and Trends program. They also sampled in other harbors, open water, and tributaries of the Bay. These samples are in the process of being analyzed for chemistry concentrations (PAHs, other organic chemicals, and metals), toxicity, and benthic community structure.[47] Although the Status and Trends program is not focused on answering specific questions about marinas, the marina samples will add to the body of knowledge about marinas in the Bay.
    b. **Bay Protection and Toxic Cleanup Program (BPTCP) (California State Water Resources Control Board [State Board] and San Francisco Regional Water Quality Control Board [San Francisco Regional Board]).** The objective of the toxic hot spot program was to identify toxic hotspots in the Bay. The first stage of this was a toxic hotspot study, which focused on the most polluted areas in the Bay, which were assumed to be those areas located downstream from historical or present pollution sources. This limited researchers' ability to investigate each site in detail. First, toxicity-screening tests were conducted on samples from various stations throughout the Bay's near shore areas.[48] Five marinas sites were included.[49] Researchers then returned to those sites found to be significantly toxic and investigated further with chemical analysis (metals, PAHs and other organic chemicals), and benthic community analysis. Out of the marina areas sampled, three had measurable biological (toxic) impacts, but contaminant levels were low or not measured. In the other two marinas contaminant levels, toxicity levels, and benthic degradation were either low (below thresholds) or were not measured.[50] In Gashouse Cove marina in San Francisco and Richmond

Harbor, nickel values were elevated. However, nickel is known to occur naturally throughout the Bay, so marina-related activities are most likely unrelated. At the conclusion of this study, the five marinas studied were not found to be toxic hotspots in the Bay. Because this program does not focus on answering questions about marinas, and the small amount of testing in marinas was not investigated further, no conclusions about marina quality conditions can be made.

c. **Sediment Testing for Maintenance Dredging.** Metals data exist for marinas that have conducted sediment testing for maintenance dredging and disposal, but these data have not been compiled or sufficiently analyzed for marina impacts. Chemical, physical, and bioassay testing of sediment samples are conducted to determine suitability of the dredged material for in-bay disposal. This is required by several agencies in the Bay Area and the Dredged Materials Management Office (DMMO), including BCDC, the San Francisco Regional Board, and the U.S. Army Corps of Engineers. Samples are taken at depths equal to dredging depths rather than the top few centimeters of sediment. This introduces uncertainty as to whether contamination is marina-related or historical.

**Petroleum Hydrocarbons**

1. **Summary.** Petroleum hydrocarbons contaminate waters and sediments throughout San Francisco Bay, and research is underway to determine the extent of these and other contaminants' effects on the ecosystem. Marina and recreational boating-related activities have potential to introduce petroleum hydrocarbons to Bay waters, specifically within marina basins. While studies have been conducted in Southern California and worldwide (See Appendix B for studies outside of California), there are few studies on petroleum hydrocarbons in marinas of San Francisco Bay. Studies identified by this literature review suggested that petroleum hydrocarbons are a potential problem that deserved further investigation in San Francisco Bay marinas. BCDC's Pilot Study has begun to fill this gap by sampling and analyzing sediments in four San Francisco Bay marinas (See Appendix A). The following sections provide a description of petroleum hydrocarbons, effects on marine life, potential sources and pathways in marinas, and conclude by documenting existing studies on petroleum hydrocarbons in California and San Francisco Bay marinas.
2. **Description of Petroleum Hydrocarbons.** Petroleum hydrocarbons are a group of organic molecules that can be subdivided into straight-chain alkenes, branched alkanes, cycloalkanes, and aromatics. Heavier, non-water soluble petroleum hydrocarbons sorb readily to particulate matter and suspended sediments, and accumulate in bottom sediments,51 often near points of entry of the sediments.52 These include the high-

molecular weight polycyclic aromatic hydrocarbons (PAHs), which degrade very slowly and persist in the environment (alkanes and cycloalkanes break down rapidly). They can be re-suspended in the water column through activities such as dredging, boat propellers, or benthic organism activity. Lower-molecular weight aromatics, such as toluene and xylene, are more likely to be found in the water column, but are often lost to evaporation and dissolution after spills.53

3. **Effects of Petroleum Hydrocarbons on Marine Life.** When estuaries and shallow coastal marine environments are exposed to oil pollution, benthic communities can experience dramatic changes. Fine grained sediments in these habitats sorb hydrocarbons and other components of oil, and can re-release the contaminants over years (from disturbance of the bottom due to storms, dredging, or boat propellers, for example). This can arrest the development of benthic communities. Biota can experience lethal and sublethal effects from oil contamination. Lethal effects result from organisms being smothered, trapped or suffocated by a spill. Sublethal effects can result from doses to juveniles and eggs, which in turn affect the community's reproduction, growth, distribution, and behavior, which in turn affect species composition, abundance, and diversity (See Table 1). Effects of Polycyclic Aromatic Hydrocarbons (PAHs) (see "Description of Petroleum Hydrocarbons" above), on marine organisms and biotic communities vary widely in nature, depending on bioavailability of contaminants and the capacity of organisms to metabolize them. In general, dissolved hydrocarbons in the water column are the most bioavailable to organisms, followed by those in the tissues of marine organisms (if they are eaten by other organisms), followed by PAHs in sediments.[54] Since PAHs do not dissolve well in water, benthic organisms are particularly susceptible to PAHs in the sediment. However, compounds can be re-suspended in the water column by bottom currents, bioturbation, etc. Some marine organisms, such as bivalve mollusks and echinoderms, do not metabolize PAHs efficiently, causing PAHs to accumulate to high levels in their tissues. Unmetabolized PAHs can be acutely toxic to marine organisms,[55] causing mollusks to develop neoplasia (tumors), for example. Other marine organisms, such as fish, tend to rapidly metabolize PAHs, and accumulate the contaminants only when exposed to heavily polluted environments. It has also been shown, however, that metabolized PAHs (e.g. epoxides and dihydrodiols) can be damaging, because the reactive metabolites of the PAHs have the ability to bind to cellular proteins and DNA, causing biochemical disruptions and cell damage that lead to mutations, developmental

malformations, tumors, and cancer. For example, the development of hepatic neoplasms in bottom-dwelling fish has been linked to PAH concentrations in sediments. Fish exposed to PAHs have also developed lesions. [56] Recent laboratory studies on zebra fish (*Danio rerio*) show that arrhythmia and loss of cardiovascular function are major effects from PAH exposure (See Table 1).[57]

Other types of petroleum hydrocarbons include benzene, toluene, and xylene, which are water soluble compounds. They can kill organisms in the water column, such as meroplankton,[58] and ichthyoplankton.[59] However, much of the lower-molecular weight aromatics, such as toluene and xylene, are often lost to evaporation and dissolution, making them less of a threat.[60]

4. **Petroleum Hydrocarbons in San Francisco Bay.** The RMP has been tracking the status and trends of contaminants in San Francisco Bay since 1993. It is important to note that sample stations are located primarily in the middle of the Bay, and not the margins where the marinas are located (recent study design changes include more near-shore area sampling sites). In water samples collected from 1997-2001 PAHs frequently exceeded water quality objectives in South Bay sampling stations. PAHs, along with mercury and PCBs, accounted for most of the violations of water quality guidelines in the Bay.61,62 Castro Cove, Richmond, the Central Basin, Islais Creek, Oakland Inner Harbor, and San Leandro Bay, are listed on the State's 2002 303 (d) list for PAHs in sediment.63 In San Francisco Bay as a whole, PAHs are listed on the State's 2002 303 (d) monitoring list.64

   PAHs tend to accumulate in bottom sediments, sorb to suspended sediments, and accumulate in organisms at the base of the food web in the San Francisco Estuary. These PAHs pose acute hazards to invertebrates living in the sediments, and these invertebrates are important food sources for various fish species.[65]

5. **Potential Sources and Pathways of Petroleum Hydrocarbons in Marinas.** According to calculated averages from the National Resource Council's 2002 Oil in the Sea Report for 1990-1999, recreational marine vessels with older carbureted 2-stroke engines are the third largest source (approximately 2.1%, 5.6 thousand tons per year) of petroleum hydrocarbons released in North American waters per year, out of a total of 260,000 tons. Land-based sources (river and runoff) contribute the most (twenty-one percent), and atmospheric deposition accounts for the second largest source (eight percent). Recreational vessels with carbureted two-stroke engines release slightly more than large tanker oil spills, which release 5.3 thousand tons per year.66 These older engines are

currently being phased out for cleaner direct injected two-stroke engines, and many boaters in San Francisco Bay utilize cleaner burning four cycle engines.

Petroleum hydrocarbons comprise more than seventy-five percent by weight of most crude and refined oils.[67] They are also contained in gasoline and other products such as grease, lubricants, finishes, and cleansers. Likely marina-related sources include fueling stations, boat engine maintenance areas, engine operation, and storm water runoff from adjacent parking lots, rooftops and upland areas.[68] For example, maintenance work conducted in marina parking lots and improper disposal of oil and other hazardous materials can increase contaminated runoff.[69] Additionally, gasoline can be spilled into the water during fueling, or through accidental/inadvertent leaks. Two-stroke engines release unburned fuel and exhaust gases into waters because they are designed to accomplish fuel intake and exhaust in the same cycle. They also have lubricant oil mixed in with fuel, which can be released along with the unburned fuel.[70] Older carbureted two-stroke engines are responsible for approximately two percent of petroleum hydrocarbons in North American waters each year,[71] although these numbers may be decreasing as these engines are phased out for cleaner direct injected two-stroke engines. Petroleum hydrocarbons contained in bottom sediments can be reintroduced to the water column through dredging, boat propeller action, construction activities, or other activities that stir up the bottom sediments (See Table 1).

Water in a boat's bilge can become contaminated with oil or fuel from maintenance related spills or leaks in hoses, seals, and/or gaskets. Contaminated bilge water can then enter marina waters through inadvertent automatic bilge pump discharges or boaters pumping oily bilge water overboard. This practice is illegal, but enforcement by the U.S. Coast Guard is minimal due to limited resources. Sunken and flooded vessels also leak oil and fuel into marina waters (See Table 1).[72]

Particularly toxic forms of petroleum hydrocarbons, PAHs, are contained in both crude and refined petroleum. They are also contained in creosote treated wood, which is often used in submerged pilings and boat docks, and may be a source of PAH contamination.[73] A study conducted by the U.S. Navy, in a naval base in San Diego, found PAHs in the water, which were attributed to weathered creosote from old pier pilings. These levels had decreased due to the removal and replacement of the pilings (See Appendix B for more studies documenting petroleum hydrocarbons in marinas) (See Table 1).[74] BCDC is considering the prohibition of creosote treated wood in the Bay unless it is wrapped in a manner acceptable to the Regional Board and maintained continually.

Additionally, petroleum hydrocarbons may occur in wastewaters, atmospheric discharges from the burning of fossil fuels, urban runoff, agricultural runoff, asphalt production, waste incineration, forest and brush fires and volcanic eruptions.[75]

6. **Petroleum Hydrocarbons in California Marinas.** Southern California studies have documented the presence of petroleum hydrocarbons in marinas. The Southern California Bight '98 Regional Monitoring Survey found that the highest sediment concentrations for PAHs and other target analytes (metals, chlordanes, and PCBs) were in bays and harbors, with marinas accounting for a significant portion. PAHs in marinas were not found to be as high as PAHs in port and industrial harbors, however.76
7. **Petroleum Hydrocarbons in San Francisco Bay Marinas.** At the time of this literature review, little was known about the extent of petroleum hydrocarbon contamination in San Francisco Bay marinas. The following paragraphs briefly describe three monitoring efforts that included sampling for petroleum hydrocarbons in San Francisco Bay marinas.77
    a. **MTBE Impacts on Marine Water Quality.** Bay et al (2000) examined the fate and effects of Methyl-*tert*-butyl ether (MTBE), a fuel additive used to reduce exhaust emissions, in the marine environment. Researchers sampled receiving waters of assumed MTBE inputs: publicly owned treatment works (POTWs) (waste water treatment plants) and oil refineries. Three marinas in San Francisco Bay were sampled, including one in Redwood Creek, in Martinez and in Oakland. MTBE was detected at a frequency of seventy-five to one hundred percent, with a range of 0.9-1.6 μg/L. No MTBE was detected in the receiving waters of POTWs and oil refineries.[78] While concentrations in marinas were not high enough to cause toxic effects (the threshold for toxic effects in most sensitive species [amphipod] was 37,000 μg/L), this study points out that fuel spills are a potential issue at marinas. Similar patterns were found throughout California. MTBE contamination was most extensive in San Diego and Mission Bays, with most occurring at marinas (these Bays have no POTWs or refineries). Watercraft with carbureted two–stroke engines were cited as the likely source of the MTBE contamination throughout the California sites studied.[79]
    b. **NOAA National Status & Trends Bioassessment Program.** In 2000 and 2001, researchers for NOAA sampled sediment at five marina stations in San Francisco Bay, as part of their regional Status and Trends program (see Metals in SF Bay

Marinas sections for more information on this study). Preliminary results have found PAHs in marinas as well as other areas sampled.[80] This information provided further indication that PAHs should be investigated in SF Bay marinas. The data helped to inform BCDC's Pilot Study.

c. **Bay Protection and Toxic Cleanup Program (BPTCP).** The "Metals in San Francisco Bay Marinas" section (Page 23) provides a full description of this program. Gashouse Cove Marina in San Francisco was listed as a 'site of concern' for PAHs for the BPTCP.[81] Because of the historical activity at this site, however, it is difficult to isolate the marina as a source.

**Sewage/Bacterial Contamination**

1. **Summary.** Current bacteriological monitoring efforts in San Francisco Bay do not focus exclusively on marinas, or contributions from marinas and recreational boating. Since existing monitoring efforts are done mainly on a monthly basis, clear trends in contamination are not known. Additionally, biological monitoring results are inherently variable, and it is difficult to ascertain clear trends or sources of contamination in the absence of taking large amounts of daily samples. Some marina studies in other parts of the country (e.g. Fisher et al, see Appendix B) focus on intensive studies over peak use periods, such as holiday weekends. The following sections provide a description of sewage/bacterial contamination, effects on marine life, potential sources and pathways in marinas, and conclude by documenting existing studies on sewage/bacterial contamination in California and San Francisco Bay marinas.
2. **Description of Sewage/Bacterial Contamination.** Sewage discharges can be in the form of raw sewage or treated sewage. Raw sewage is 99 percent water, with the remainder consisting of solid waste (e.g. sediment, floatables, plastics), suspended and dissolved organic matter, oil and grease, nutrients, and pathogens (bacteria, viruses, protozoa, and helminthes [parasitic worms]). When measuring possible sewage contamination, scientists generally look for the presence of bacterial indicators by counting colonies of total coliform, fecal coliform, Escherichia coli, or enteroccocus. These indicator species signal the presence of other fecal matter, which may signal the presence of pathogens (disease-carrying micro-organisms).82
3. **Effects of Sewage/Bacterial Contamination on Marine Life and Human Health.** Sewage discharges can cause eutrophication, or algal blooms (which can also be caused by nitrogen and phosphorus - see "Nutrients" section) in marine waters. Organic matter contained in sewage can exacerbate anoxic and hypoxic conditions by increasing biochemical oxygen demand, which is oxygen consumed during the microbial

decomposition of the waste. Elevated bacterial levels from sewage can lower dissolved oxygen levels (affecting aquatic organism survival) from increased biological oxygen demand. One North Carolina study of marinas found that marinas had significantly lower dissolved oxygen levels than adjacent water bodies, due to poor flushing within the marina basins, and high biological demand, attributed to boat sewage discharges (See Table 1).83

Pathogens contained in sewage pose potential health risks to humans. Those exposed to sewage-contaminated water can get hepatitis, dysentery, gastroenteritis, parasitic infections and even typhoid. Consuming raw or improperly cooked oysters, mussels or clams also presents a risk (See Table 1).[84]

4. **Sewage/Bacterial Contamination in San Francisco Bay.** San Francisco Bay is listed as an impaired water body on the State's 2002 303 (d) list for pathogens in the Napa and Petaluma Rivers (potential sources: agricultural, urban runoff, stormwater and construction/land development [Petaluma River]). Marina Lagoon in San Mateo (potential sources are urban runoff/storm sewers, and nonpoint sources) and Richardson Bay (source identified as substandard sewage systems in houseboat areas, urban runoff/storm sewers, septage disposal, boat discharges, vessel wastes) are listed for high coliform counts.85 Richardson Bay is a federally designated no discharge zone (NDZ). An NDZ is an area of a water body or an entire water body into which the discharge of sewage (whether treated or untreated) from all vessels is completely prohibited.86 Additionally, counties monitor beaches, and some marinas that are located next to swimming areas in the Bay, for indicator bacteria (see below: "Sewage/Bacterial Contamination in San Francisco Bay Marinas"). Warnings are posted in these recreational areas when high coliform counts are detected, to avoid health risks to swimmers. In 2000 San Francisco County had thirteen incidences of beach warnings attributed to rain events (combined sewer overflows can be a major cause of high coliform counts), but no beach closures.87 Monitoring dissolved oxygen in the Bay provides a good indicator of organic enrichment (from nutrients or poorly treated sewage, for example). The USGS has been doing this since the early 1970s. See "Nutrients in San Francisco Bay" (Page 33) for a description of this data.
5. **Potential Sources of Sewage/Bacterial Contamination in Marinas.** Understanding the sources of bacterial contamination in marine waters is a major task for scientists and policy makers.[88] The main marina and recreational boating–related source of bacterial contamination is sewage discharges from marine toilets or marine sanitation devices (MSDs) (See Table 1). Whether boats are a significant source of bacterial contamination

in marinas is a subject of great debate. Fecal bacteria can also come from birds, marine mammals, pet feces, municipal sewer outfall overflows, and leaking septic tanks.[89] Additionally, marine waters contain bacteria and viruses from natural sources.[90] It is against federal law to discharge untreated sewage within three miles of the coast. Some boaters may still discharge waste because of lack of education, or a perception that discharges are not pollution, exacerbated by the lack of convenient, accessible, easy to use pumpout facilities.[91] Some boaters treat their waste with type I and type II marina sanitation devices (MSDs). Although legal, it is still potentially harmful to discharge treated waste in marine waters because of the chemicals used and system malfunctions, and it is illegal to do so in federally designated no discharge zones (NDZs), such as Richardson Bay. A type III marine sanitation device, a holding tank, is the preferred method because it ensures that no sewage, partially treated or not, enters the water.

6. **Sewage/Bacterial Contamination in California Marinas.** This literature review found very few monitoring efforts documenting bacterial contamination in California marinas. One effort worth noting is a current vessel waste study for implementation of a fecal coliform total maximum daily load (TMDL) in Newport Bay by the Santa Ana Regional Water Quality Control Board.92 This study examined one tidally flushed marina and one sheltered marina during periods of high and low use by vessels. Samples were taken inside the marinas and in the outside channels, with approximately 20-30 sampling sites per marina. Although study reports have not been released, results will help to increase the body of knowledge on bacterial contamination at California marinas.
7. **Sewage/Bacterial Contamination in San Francisco Bay Marinas.** Because of the diffuse sources of coliform bacteria in the marine environment, and the lack of Baywide studies or continuous monitoring, the extent of marina and recreational boating-related bacterial contamination problem is still unknown and difficult to quantify in San Francisco Bay. Most current bacteriological monitoring efforts in San Francisco Bay are not focused on isolating marina and recreational boating sources. Various local environmental health departments, such as San Francisco City and County Environmental Health, San Mateo County Environmental Health, and Berkeley Environmental Health, sample monthly at some marinas, but they are mainly focused on public beaches and storm water and sewer outfalls. This is done to make sure the health of swimmers and recreationists are safeguarded, and that public health standards are not violated. The following sections summarize past, present, and future marina bacteriological monitoring efforts.

a. **1981 Vessel Waste Discharge Survey (San Francisco Regional Board).** In 1981 the San Francisco Regional Board conducted a vessel waste discharge survey in sixteen marina areas in San Francisco Bay, to see if they violated the bacteriological water quality objectives for water contact recreation and shellfish harvesting. Recommendations included the proper sewering of houseboats and liveaboards, which represented sites of continuous violations, and the increased installation and use of sewage pumpout facilities.[93] Many marinas have now installed sewage pumpout facilities and/or contracted with mobile pumpout services. BCDC requires all new and expanding marinas in San Francisco Bay to install sewage pumpout facilities, and to have adequate restroom facilities on shore (to discourage people from using their boat toilets). Several clean marina educational programs distribute maps to boaters depicting the location of sewage pumpout facilities (see the California Department of Boating and Waterways, the Boating Clean and Green Campaign, and the San Francisco Estuary Project).

b. **Richardson Bay Regional Authority (RBRA).** For over ten years, the Richardson Bay Regional Authority (RBRA) and the San Francisco Regional Water Quality Control Board have undertaken a bacteriological monitoring program, with monitoring sites at marinas, to see whether Richardson Bay, a federally designated no-discharge zone, is in compliance with the state's water quality objectives. While certain areas have demonstrated random spikes in bacteria levels, it is difficult to track down the source of the problems. Therefore, in addition to monitoring activities, other proactive efforts in Richardson Bay are being undertaken, such as providing a mobile pumpout service, encouraging replacement of old sewage lines for permitted houseboats, and working with un-permitted houseboats, liveaboards and recreational boats to manage waste.[94]

c. **Water Keepers Northern California/San Francisco BayKeeper.** San Francisco BayKeeper, under a State Coastal Nonpoint Source Prop 13 grant, is gearing up for a three-year bacteria study of four marinas in San Francisco Bay. It will characterize indicator bacteria levels during dry and wet season months, and analyze the relative contributions of indicator bacteria from boating activities and storm water inputs. Not only will this give a better picture of problems at marinas, but it will also help to ascertain potential sources if problems are identified.

BCDC is collaborating with both of these sampling efforts, so that future data and reports can inform its marina and water quality programs. Both representatives from Water Keepers and RBRA sit on the SF Bay Marinas and Recreational Boating Nonpoint Source Task Force.

**Nutrient Enrichment: Nitrogen and Phosphorus**

1. **Summary.** Excessive nutrients can pose dangers to the health of estuarine ecosystems, including San Francisco Bay. While marinas and boating activities can introduce nutrients into the Bay, there are no existing monitoring efforts to date examining this potential issue. Due to funding limitations, BCDC did not include nutrients as part of its Pilot Study. If future funding becomes available, BCDC or other agencies, such as the Regional Water Quality Control Board, should consider monitoring for nutrients in SF Bay marinas. The following sections provide a description of nutrient enrichment, effects on marine life, potential sources and pathways in marinas, and conclude by documenting existing studies on nutrient enrichment in California and San Francisco Bay marinas.
2. **Description of Nutrients.** At least half of the nation's waters do not adequately support aquatic life because of excess nutrients, specifically nitrogen and phosphorus. While both elements are essential for life, excessive nutrient enrichment can cause eutrophication in waters, affecting the natural functioning of ecosystems. Nitrogen is the primary nutrient responsible for eutrophication in temperate estuaries, while phosphorus is a critical element in tropical estuarine and coastal systems.[95]
3. **Effects of Nutrients on Marine Life.** Coastal areas tend to trap much of the nutrients originating from land-based sources (e.g. agricultural fertilizers, sewage treatment plants). Nutrient-enrichment of waters can result in eutrophication and algal blooms, causing low dissolved oxygen of bottom waters, fish kills, and the depletion of desirable flora and fauna.96 Toxic phytoplankton blooms are called "red tides", and these can cause mass mortality of invertebrates and fish.97 (See Table 1)
4. **Nutrients in San Francisco Bay**. According to the United States Geological Service (USGS), San Francisco Bay receives more than 800 million gallons of municipal wastewater containing 60 tons of nitrogen daily.98 Monitoring dissolved oxygen in the Bay provides a good indicator of organic enrichment (from nutrients or poorly treated sewage, for example). The USGS has been doing this since the early 1970s. Since 1993, dissolved oxygen data have shown that Bay waters have sufficient oxygen to sustain the most sensitive marine species. This is a marked improvement from the 1950s and 60s, before the Clean Water Act began regulating wastewater inputs. Summer oxygen

depletions below 5mg/L, especially in the South Bay (nutrient inputs from cannery waste and ammonia, which contains nitrogen) were common through the 1970s. Advanced wastewater processes have vastly improved the oxygen levels in the Bay by reducing the inputs of oxygen-consuming wastes.99 For example, the implementation of advanced wastewater treatment in 1979 immediately reduced the input of ammonia-nitrogen to South San Francisco Bay.100 The Napa and Petaluma Rivers (including their tidal portions), are listed on the State's 2002 303 (d) list for nutrients. The potential source in the Napa River is agriculture. Potential sources in the Petaluma River include agriculture, construction/land development, and urban runoff/storm sewers.101 Other smaller localized areas, such as marinas, may suffer from low dissolved oxygen, however (see below).

5. **Potential Sources of Nutrients in the Marina Environment.** Many detergents used in vessel cleaning, and in on-board kitchens and bathrooms contain nutrients such as nitrogen and phosphorus. Grey water containing these detergents is sometimes discharged at marinas, and inadvertent spills can occur during topside cleaning activities. Sewage also contains nutrients. Additionally, runoff from landscaped areas at the marinas can contain nutrients from fertilizers. Stormwater runoff from upland sources (e.g. agricultural fertilizers) can also contain nutrients.102,103 (See Table 1)
6. **Nutrients in California Marinas.** This literature review found very few monitoring efforts that document nutrient levels in marinas, although dissolved oxygen monitoring efforts might exist. In California, the Lake Tahoe Regional Water Quality Control Board monitors nutrients in marinas in Lake Tahoe. Nitrogen and Phosphorus levels are consistently above water quality standards (0.15 mg/L and 0.008 mg/L respectively), especially in those closed basin marinas that have limited water flushing capabilities. These water quality conditions could be due to grey water discharges, detergents from boat washing, landscaping fertilizers combined with over-watering, waterfowl feces, domestic animal wastes, and urban runoff from streets that are sanded (contains phosphorus).104
7. **Nutrients in San Francisco Bay Marinas.** This literature review found no monitoring efforts examining nutrients or dissolved oxygen levels in San Francisco Bay marinas. Due to funding limitations and limited staff time, BCDC did not include nutrients (e.g. nitrogen and phosphorus) as part of its Pilot Study. Basic water quality parameters, including dissolved oxygen measurements, were taken during sediment sampling at the four marinas selected for the study (see Appendix A). However, these water measurements represent only a snapshot in time. Dissolved oxygen levels naturally

fluctuate throughout the day. In order to get accurate assessments of dissolved oxygen trends, it is necessary to take multiple measurements at different times of day, and during different tidal regimes. Additional monitoring of oxygen levels is recommended to improve our understanding of oxygen saturation conditions in marinas. San Francisco BayKeeper will be taking readings of basic water quality parameters (temperature, dissolved oxygen, pH, and salinity) as part of its bacteria sampling program.

**Table 1. Marina Related Pollutants, Sources, Pathways, and Impacts**

| Pollutant | Potential Marina & Recreational Boating-related Sources | Potential Marina & Recreational Boating-related Pathways | Potential Impacts to Marine Life and/or human health |
|---|---|---|---|
| **Heavy Metals** (Copper, zinc, lead, arsenic, chromium, cadmium, tributyltin) | Marine/ boat hull paints, engine components, wood preservatives for pilings and docks, engine oils, boat plating accessories | Runoff from maintenance areas, boatyards, and parking lots. In – water leaching of boat hulls, pilings, and docks. Under-water hull cleaning. Boat bilge discharges. | Marine Life: Bioaccumulation in marine food chain; risk to reproductive & central nervous systems; pathological responses (e.g. developmental changes & growth abnormalities); effects on biotic communities. |
| **Petroleum Hydrocarbons** (oil, fuel, PAHs) | Fuel, oil, grease, lubricants, finishes, cleansers, 2-stroke engines; creosote treated wood. | Fuel and oil spills from fueling areas, inadvertent leaks, 2-stroke engines. Oil & fuel contaminated bilge water discharges, runoff from boat engine maintenance areas, sunken vessels leaking fuel and oil; leaching of creosote treated pilings and docks. Boat bilge discharges. | Marine Life: Oil-arrested development benthic communities, lethal effects from smothering, sublethal effects to juveniles & eggs.<br>PAHs-very toxic. Carcinogenic, mutagenic, teratogenic; reproductive failure, reduced growth & fecundity. |
| **Bacterial Contamination** | Human wastes from recreational boaters. | Direct discharges and overboard discharges from marine toilets, marine sanitation devices, and on-shore facilities | Marine Life: Eutrophication, anoxic, and hypoxic conditions of marine waters-> lowers dissolved oxygen levels-> affects survival of aquatic organisms. Org. loading from sewage also affects macrobenthic communities.<br>Human risks from pathogens: dysentery, hepatitis, typhoid, gastroenteritis, and parasitic infections |
| **Nutrients** (Nitrogen, Phosphorus) | Detergents; fertilizers | Grey water discharges, vessel cleaning and maintenance activities, illegal use of detergents on oil spills and in bilge; runoff from fertilized landscaped areas. | Eutrophication; algal blooms; toxic red tides->lower dissolved oxygen levels, reduced light penetration in water->impacts survival of aquatic life. Affects macrobenthic communities |

## Chapter 2 Endnotes

[1] U.S. Environmental Protection Agency (USEPA). 2001. *National Management Measures Guidance to Control Nonpoint Source Pollution from Marinas and Recreational Boating*. Nonpoint Source Control Branch, Office of Wetlands, Oceans and Watersheds, Office of Water, U.S. Environmental Protection Agency. November 2001.
[2] SWRCB & CCC 2000. *Plan for California's Nonpoint Source Pollution Control Program.* California State Water Resources Control Board, Sacramento, CA and California Coastal Commission, San Francisco, CA.
[3] It is important to note that the Pilot Study (see Appendix A) focuses on determining if pollutants are present in marinas, and is not a detailed source study. However, by careful selection of marinas for the pilot study to isolate out as much as possible different sources, and by looking to the literature, one can start to make inferences as to possible sources of contamination in those marinas sampled.
[4] See BCDC 2003. *Water Quality Protection and Nonpoint Source Pollution Control in San Francisco Bay*. San Francisco Bay Conservation and Development Commission. San Francisco, CA for overview and policies on other categories of nonpoint source pollution in BCDC's jurisdiction.
[5] Pollutants can enter estuaries such as San Francisco Bay through multiple point and nonpoint *sources* (activities leading to the release of contaminants contained in boat hull paints, automobile combustion byproducts, and pesticides) and numerous *pathways* (routes through which contaminants are transported such as direct water contact with the product [boat hull paints], urban and agricultural runoff). For purposes of this chapter, the term 'sources' encompass both sources and pathways.
[6] Kennish, Michael J. 1998. *Pollution Impacts on Marine Biotic Communities.* CRC Press. Boca Raton & New York.
[7] U.S. EPA 2001
[8] Kennish 1998
[9] Kennish 1998.
[10] Remineralization in sediments is the release of organically bound contaminants (metals and organics) to pore water during the bacterial breakdown of sediment organic matter. This process is most active in the shallow oxic layers of the sediment surface. See Jahnke, RA, Reimers, CE and Craven, DB. 1990. Intensification of recycling of organic matter at the sea floor near ocean margins. Nature, 348, 50-54
[11] Hinkey, Lynne Marie 2001. "A Baseline Assessment of Environmental Conditions and the potential for Polycyclic Aromatic Hydrocarbons (PAHs) Biodegradation in Marina Waters and Sediments." A thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Marine Sciences (Chemical Oceanography) University of Puerto Rico. Mayaguez Campus.
[12] SDRWQCB. 2003. DRAFT Basin Plan Amendment and Technical Report for Dissolved Copper in the Shelter Island Yacht Basin. California Regional Water Quality Control Board, San Diego Region. January 31, 2003
[13] Nickel and chromium are naturally high in San Francisco Bay because of the types of soils and rocks within the watershed. They do not appear to be causing harm in the estuary (see SFEI 2000 for more information).
[14] California does not currently have regulatory sediment quality objectives like it does with water quality objectives in its "Basin Plans." Guidelines referred to here are based on Long, E.R., D.L. MacDonald, S.L. Smith and F.D. Calder. 1995. *Incidence of Adverse Biological Effects Within Ranges of Chemical Concentration in Marine and Estuarine Sediments.* Environmental Management. 19 (1): 81-97. "Effects Range Low" (ERL) guidelines (in mg/kg dry weight): copper (34), chromium (81), nickel (20.9), mercury (0.15), lead (46.7), zinc (150). Based on
[15] SFEI. 2003. *Pulse of the Estuary: Monitoring and Managing Contamination in the San Francisco Estuary*. SFEI contribution 74. San Francisco Estuary Institute (SFEI), Oakland, CA.
[16] 2002 CWA Section 303 (d) List of Water Quality Limited Segments. San Francisco Bay Regional Water Quality Control Board. Approved by U.S. EPA July 2003.
[17] CWA Section 303 (d) Monitoring List 2002. July 2003.
[18] METRO. 1992. *Maritime industrial waste project: Reduction of toxicant pollution from the maritime industry in Puget Sound.* Municipality of Metropolitan Seattle Water Pollution Control Department, Industrial Waste Section, Seattle, Washington.
[19] MBNMS 1996. Action Plan III: Marinas and Boating. Water Quality Protection Program for Monterey Bay National Marine Sanctuary.
[20] See Schiff, Kenneth C., Dario Diehl, and Aldis Valkirs. 2003. *Copper Emissions from Antifouling Paint on Recreational Vessels.* Technical Report 405. Southern California Coastal Water Research Project. June 2003; and SDRWQCB. 2003. DRAFT Basin Plan Amendment and Technical Report for Dissolved Copper in the Shelter Island Yacht Basin. California Regional Water Quality Control Board, San Diego Region. January 31, 2003
[21] Metals also occur naturally in the environment, from weathering and erosion of rocks, leaching of soils, eruption of volcanoes, and emissions of deep-sea hydrothermal vents. Anthropogenic sources are much greater in coastal waters near urban centers, however (Source: Kennish, Michael J. 1998. *Pollution Impacts on Marine Biotic Communities.* CRC Press. Boca Raton & New York).
[22] Schiff et al 2003
[23] SDRWQCB 2003
[24] Schiff 2003
[25] USDA 2000. *Environmental Impact of Preservative-Treated Wood in a Wetland Boardwalk.* USDA Forest Service, Forest Products Lab, Madison, WI
[26] Personal communication with Dale Hopkins, San Francisco Regional Board, 10/2003
[27] Santa Monica Bay Restoration Commission, Marina Del Rey Clean Marina Program
[28] U.S. EPA. 1994. *Aquatic Toxic Information Retrieval Database.* U.S. Environmental Protection Agency, Environmental Research Laboratory. Electronic Bulletin Board.
[29] MBNMS 1996
[30] SWRCB. 1988. *Tributyltin: A California Water Quality Assessment.* California State Water Resources Control Board, Division of Water Quality. Report #88-12
[31] U.S. EPA 2001
[32] Hinkey 2001
[33] U.S. Environmental Protection Agency (USEPA). 2001. *National Management Measures Guidance to Control Nonpoint Source Pollution from Marinas and Recreational Boating*. Nonpoint Source Control Branch, Office of Wetlands, Oceans and Watersheds, Office of Water, U.S. Environmental Protection Agency. November 2001.

[34] Hinkey, Lynne Marie 2001. "A Baseline Assessment of Environmental Conditions and the potential for Polycyclic Aromatic Hydrocarbons (PAHs) Biodegradation in Marina Waters and Sediments." A thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Marine Sciences (Chemical Oceanography) University of Puerto Rico. Mayaguez Campus.
[35] Washington State Department of Ecology (a). 2001. Concentrations of Selected Chemicals in Sediments from Harbors in the San Juan Islands. Publication No. 01-03-007.
[36] U.S. EPA 2001
[37] Texas Water Commission (TWC). *Marina Impacts in Clear Lake and Galveston Bay.* Report No. D7-001. Houston, TX.
[38] Hinkey 2001; EPA 2001
[39] U.S. EPA 2001
[40] Noblet, James A., Eddy Y. Zeng, Rodger Baird, Richard W. Gossett, Robert J. Ozretich, and Charles R. Phillips. 2003. *Southern California Bight 1998 Regional Monitoring Program: VI. Sediment Chemistry.* Southern California Coastal Water Research Project (SCCWRP). Westminster, CA.
[41] Bay, Steven M., David Lapota, Jack Anderson, Jeff Armstrong, Tim Mikel, Andrew W. Jirik, Stanford Asato. *S. CA Bight 1998 Regional Monitoring Program: Vol. IV. Sediment Toxicity.* Southern California Coastal Water Research Project (SCCWRP).
[42] Johnston, R.K. 1990. The Use of Marine Fouling Communities to Evaluate The Ecological Effects of Pollution. Technical Report 1349. Space and Naval Systems Center. Systems Center (SPAWAR). San Diego, CA.
[43] Johnston, R.K. 1990. The Use of Marine Fouling Communities to Evaluate The Ecological Effects of Pollution. Technical Report 1349. Space and Naval Systems Center. Systems Center (SPAWAR). San Diego, CA.
[44]California Toxics Rule for dissolved copper is 3.1 mg Cu/L for continuous or chronic exposures (not to be exceeded over a four-day average), and 4.8 mg Cu/L for brief or acute exposures (not to be exceeded over a one-hour average).
[45]SDRWQCB. 2003. DRAFT Basin Plan Amendment and Technical Report for Dissolved Copper in the Shelter Island Yacht Basin. California Regional Water Quality Control Board, San Diego Region. January 31, 2003
[46] SDRWQCB 2003
[47] Personal communication with Ian Hartwell, National Oceanic and Atmospheric Administration (NOAA) 1/03
[48] Personal communication with Karen Taberski, San Francisco Bay Regional Water Quality Control Board, 1/03
[49] Personal communication with Russell Fairey, Moss Landing Marine Labs, Marine Pollution Studies Lab, 1/03
[50] Hunt, J.W., B.S. Anderson, B.M. Phillips, J. Newman, R.S. Tjeerdema, K. Taberski, C.J. Wilson, M. Stephenson, H.M. Puckett, R. Fairey, and J. Oakden. 1998. *Sediment Quality and Biological Effects in San Francisco Bay.* California State Water Resources Control Board. Sacramento, CA. 188 pp.
[51] Kennish, Michael J. 1998. *Pollution Impacts on Marine Biotic Communities.* CRC Press. Boca Raton & New York.
[52] NCDEM 1991
[53] Kennish 1998
[54] NRC. 2002. *Oil in the Sea III: Inputs, Fates, and Effects.* National Research Council (NRC), Committee on Oil in the Sea: Inputs, Fates, and Effects. Ocean Studies Board and Marine Board. Divisions of Earth and Life Studies and Transportation Research Board. National Academy Press. Washington, D.C.
[55] Kennish, Michael J. 1998. *Pollution Impacts on Marine Biotic Communities.* CRC Press. Boca Raton & New York.
[56] Kennish 1998
[57] Tracy Collier, NOAA Seattle, State of the Estuary conference presentation, October 2003
[58] Any of various organisms that spend part of their life cycle, usually the larval or egg stages, as plankton
[59] Fish eggs and larvae
[60] Kennish 1998
[61] In RMP samples collected from 1997-2001, 61% of water samples had contaminant concentrations exceeding water quality objectives for at least one contaminant.
[62] SFEI 2003. *Pulse of the Estuary: Monitoring and Managing Contamination in the San Francisco Estuary.* San Francisco Estuary Institute (SFEI), Oakland, CA.
[63] 2002 CWA Section 303 (d) List of Water Quality Limited Segments. San Francisco Bay Regional Water Quality Control Board. Approved by U.S. EPA July 2003.
[64] CWA Section 303 (d) Monitoring List 2002. July 2003.
[65] SFEI. 2000. *Pulse of the Estuary: Monitoring and Managing Contamination in the San Francisco Estuary.* San Francisco Estuary Institute, Oakland, CA.
[66]NRC 2002
[67] Kennish 1998
[68] U.S. Environmental Protection Agency (USEPA). 2001. *National Management Measures Guidance to Control Nonpoint Source Pollution from Marinas and Recreational Boating.* Nonpoint Source
[69] MBNMS 1996. Action Plan III: Marinas and Boating. Water Quality Protection Program for Monterey Bay National Marine Sanctuary.
[70] Texas Water Commission (TWC). *Marina Impacts in Clear Lake and Galveston Bay.* Report No. D7-001. Houston, TX.
[71] NRC 2002
[72] MBNMS 1996
[73] Washington State Department of Ecology (a). 2001. Concentrations of Selected Chemicals in Sediments from Harbors in the San Juan Islands. Publication No. 01-03-007.
[74] Katz, C.N. 1998. Seawater Polynuclear Aromatic Hydrocarbons and Copper in San Diego Bay. Technical Report 1768. Space and Naval Systems Center. Systems Center (SPAWAR). San Diego, CA.
[75] Kennish 1998
[76] Noblet, James A., Eddy Y. Zeng, Rodger Baird, Richard W. Gossett, Robert J. Ozretich, and Charles R. Phillips. 2003. *Southern California Bight 1998 Regional Monitoring Program: VI. Sediment Chemistry.* Southern California Coastal Water Research Project (SCCWRP). Westminster, CA
[77] BCDC's Pilot Study: Condition of Sediments in Selected Marinas in San Francisco Bay (Appendix A) examines PAH concentrations in sediments of four San Francisco Bay marinas.
[78] MTBE is now banned in California
[79] Bay, Steven M. Brown, Jeffrey S. 2000. *Assessment of MTBE Discharge Impacts on California Marine Water Quality Final report for*

*SWRCB*. Southern California Coastal Water Research Project, Westminster, CA.
[80] Personal communication with Ian Hartwell, NOAA, 1/03
[81] San Francisco Regional Board. 1997. Proposed Regional Toxic Hotspot Plan
[82] Largier, John. 2002. *Beach Water Pollution: Learning What We Need to Know*. California Coast and Ocean. Winter 2002-2003.
[83] NCDEM. 1990. *North Carolina Coastal Marinas: Water Quality Assessment*. North Carolina Department of Environment, Health, and Natural Resources. Division of Environmental Management. Report #90-01.
[84] Kennish 1998
[85] 2002 CWA Section 303 (d) List of Water Quality Limited Segments. San Francisco Bay Regional Water Quality Control Board. Approved by U.S. EPA July 2003.
[86] see http://www.epa.gov/owow/oceans/regulatory/vessel_sewage/
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[100] U.S. Department of Interior, United States Geological Survey (USGS), Fact Sheet FS-053-95
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[103] Other significant sources of nutrients include municipal and industrial wastewaters, agricultural and urban runoff, dredging and dredged-spoil disposal operations (Kennish 1998)
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